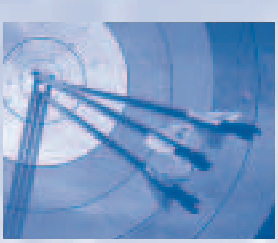
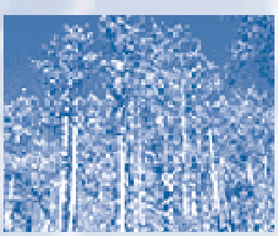
CLIMATE LEADERS GREENHOUSE GAS INVENTORY PROTOCOL

CORE MODULE GUIDANCE

Direct Emissions from the Cement Sector





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CLIMATE LEADERS
U.S. Environmental Protection Agency

This Guidance is based on the World Resources Institute and the World Business Council for Sustainable Development's GHG Protocol Initiative

The Climate Leaders Greenhouse Gas Inventory Protocol is based on the Greenhouse Gas Protocol (GHG Protocol) developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The GHG Protocol consists of corporate accounting and reporting standards and separate calculation tools. The Climate Leaders Greenhouse Gas Inventory Protocol is an effort by EPA to enhance the GHG Protocol to fit more precisely what is needed for Climate Leaders. The Climate Leaders Greenhouse Gas Protocol consists of the following components:

- Design Principles Guidance
- Core Modules Guidance
- Optional Modules Guidance
- Reporting Requirements

All changes and additions to the GHG Protocol made by Climate Leaders are summarized in the Climate Leaders Greenhouse Gas Inventory Protocol Design Principles Guidance.

For more information regarding the Climate Leaders Program, e-mail climateleaders@epa.gov

Or visit us on the web at www.epa.gov/climateleaders

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Introduction

The cement industry emits approximately 5% of the man-made and 3% of total global carbon dioxide (CO_2) emissions[1]. The cement industry is also one of the largest emitters of CO_2 through industrial processes in the U.S. In 1999, cement production accounted for approximately 40 million metric tons of carbon dioxide equivalent emissions or roughly 13% of total U.S. industrial process emissions[2,3]. Process related CO_2 emissions within the cement sector originate from the calcination of limestone and magnesium carbonate.

A cement company participating in Climate Leaders will likely include direct emissions from mobile sources, stationary combustion, and process emissions; and indirect emissions from electricity use in their corporate greenhouse gas (GHG) emissions inventory. This guidance document addresses direct cement sector process emissions only. Separate guidance documents are available for estimating emissions from stationary combustion, mobile sources, refrigerant use, and electricity purchases. Table 1 lists the different categories of emissions from cement production and the corresponding guidance for accounting for these emissions under the Climate Leaders program.

Table 1: Categories of Emissions from Cement Production

Category of Emissions	Treatment in Climate Leaders
Emissions from quarrying equipment	**Mobile Source Guidance** Reported using *Core Module Guidance for Direct Emissions from Mobile Sources.*
Emissions from purchased electricity/steam	**Purchased Electricity Guidance** Reported using *Core Module Guidance for Indirect Emissions from Purchases/Sales of Electricity and Steam.*
Emissions from combustion of fossil fuels in kiln	**Stationary Combustion Guidance** Reported using *Core Module Guidance for Direct Emissions from Stationary Combustion Sources.*
CO_2 emissions from calcination of limestone and magnesium carbonate in kiln	**Cement Guidance** Reported using this guidance.
Emissions from combustion of other fossil fuels (e.g., used for on-site power production)	**Stationary Combustion Guidance** Reported using *Core Module Guidance for Direct Emissions from Stationary Combustion Sources.*
HFC emissions from refrigeration/AC equipment use	**Refrigeration/AC Guidance** Reported using *Core Module Guidance for Direct HFC and PFC Emissions from Use of Refrigeration and Air Conditioning Units.*

1 World Business Council for Sustainable Development, *Toward a Sustainable Cement Industry,* March 2002.

2 U.S. Environmental Protection Agency, *2002 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000,* Office of Atmospheric Programs, April 2001. EPA 430-R-02-003.

3 Total excludes CO_2 emissions from the production of masonry cement from clinker.

1.1. CO_2 from Cement Production

CO_2 is a by-product of a chemical conversion process (calcination) that is used in the production of clinker, a component used in producing cement. During the cement production process, calcium carbonate ($CaCO_3$) is heated in a cement kiln at a temperature of about 1,300°C (2,400°F) to form lime (i.e., calcium oxide or CaO) and CO_2. This process is known as calcination or calcining[4]. The process releases carbon dioxide into the atmosphere. The lime reacts with silica, aluminum and other materials to produce clinker, which is ground into a fine power and combined with small amounts of gypsum to create portland cement.

The majority of the cement produced in the United States is portland cement. However, some cement manufactures produce other cement products such as blended cements and masonry cements. Blended cements are produced by blending portland cement with other pozzolanic (cementitious) materials such as fly ash or blast furnace slag. The production of blended cements can significantly reduce a manufacture's CO_2 emissions by reducing the quantity of clinker necessary to produce a unit of cement. Masonry cement is produced from portland cement and requires more lime (CaO), potentially resulting in additional CO_2 emissions[5].

1.2. CO_2 from Cement Kiln Dust (CKD)

CO_2 emissions may also be emitted from cement kiln dust (CKD) that is not recycled into the production process. CKD is comprised of the raw materials fed into the kiln that are lost to the system or do not become part of the clinker. In many cases, CKD is collected and recycled back into the system. Any CKD that is not recycled is used for other purposes (such as in masonry cement or in road bases) or it is disposed of in landfills. CKD is produced in all cement kilns, however, the quantity produced is dependent on plant-specific operating conditions. In general, the amount of CKD produced can be estimated to be about 1.5 to 2% of the weight of clinker production.

4 Magnesium carbonate ($MgCO_3$) can also be used in clinker production. The calcination of $MgCO_3$ results in the production of MgO and CO_2.

5 If lime is produced from calcination of $CaCO_3$ (or $MgCO_3$), CO_2 emissions will result from the process. If a cement company purchases lime as CaO directly from a third party, the CO_2 emissions from lime production will be outside the boundaries of the cement company's inventory. If the cement company produces the lime onsite through calcination, then they would have to account for these additional CO_2 emissions.

Methods for Estimating CO_2 Emissions

Climate Leaders recommends two approaches to quantifying the CO_2 emissions from cement production and CKD: the clinker-based methodology and the cement based methodology. Each of these approaches is described below. Because the primary source of greenhouse gases from cement production is clinker; both approaches theoretically yield the same amount of CO_2 emissions, assuming that accurate and precise data is available.

2.1. Clinker-Based Methodology

The clinker-based approach calculates emissions from cement production based on the amount of clinker produced and the CaO and MgO content of the clinker. This method has a separate calculation for determining emissions from CKD based on the amount of CKD discarded and the calcination rate of CKD. Equation 1 presents an overview of the clinker-based approach. More explanation of emission factors and default values is provided in Section 4.

The steps involved with estimating process related CO_2 emissions from cement production with the clinker-based method are shown below.

Step 1: Determine the amount of clinker produced. Determine the quantity of clinker produced. This should be provided separately by different types of clinker if there is a significant difference in the CaO and MgO content of the different clinkers.

Step 2: Calculate the calcination CO_2 emission factor. This factor is based on the CaO and MgO content of the clinker and adjusted for direct CaO and MgO imports. More information on determining the emission factor is given in Section 4.2.

Step 3: Determine the amount of CKD discarded. If this amount is not specifically known, a default factor of 2% of clinker production can be used.

Step 4: Calculate the CKD CO_2 emission factor. This factor is based on the factor for clinker corrected for partial calcination of

Equation 1: Calculating CO_2 Emissions Using the Clinker-Based Method

$$\text{Emissions} = (P_{Cli} \times EF_{Cli}) + (CKD_D \times EF_{CKD})$$

where:

P_{Cli} = Mass of Clinker Produced

EF_{Cli} = Plant specific Emission Factor of clinker $\left(\frac{\text{mass}CO_2}{\text{mass clinker}}\right)$

CKD_D = Mass of Cement Kiln Dust Discarded

EF_{CKD} = Emission Factor of partially calcined Cement Kiln Dust $\left(\frac{\text{mass}CO_2}{\text{mass CKD}}\right)$

CKD. More detail on this correction is given in Section 4.2.

Step 5: Determine the total amount of CO_2 emissions. Apply the results of Steps 1–4 to Equation 1 to calculate the total amount of cement production process CO_2 emissions.

2.2. Cement-Based Methodology

The cement-based approach was developed to ensure that emissions estimates reflected changes to the production process, such as producing blended cements where the clinker content is reduced through the addition of pozzolans and other admixtures. Since different cements contain varying clinker fractions, cement production data should ideally be disaggregated by cement type. If this disaggregation is not possible, default clinker fractions, based on assumed cement type blends, should be used. Equation 2 presents an overview of the cement-based approach. More explanation of emission factors and default values is provided in Section 4.

The steps involved with estimating process related CO_2 emissions from cement production with the cement-based method are shown below.

Step 1: Determine the quantity of cement produced. If cement production data by cement type is possible, this should be used, since each type of cement will contain a different proportion of clinker.

Step 2: Determine the clinker content of the produced cement. The clinker content is calculated by multiplying the total amount of cement produced by the clinker content ratio. The clinker content should be provided by the facility by cement type, if available. Otherwise, a default ratio could be used, see Section 4.2. If clinker is imported or exported from the facility, a correction should be made. Subtract the imported

Equation 2: Calculating CO_2 Emissions Using the Cement-Based Method

$$\text{Emissions} = P_{Cem} \times \frac{\text{Clinker}}{\text{Cement}} \times \frac{\text{RM}}{\text{Clinker}} \times \frac{CaCO_{3\ \text{equivalent}}}{\text{RM}} \times \frac{CO_{2\ (m.w.)}}{CaCO_{3\ (m.w.)}}$$

where:

P_{Cem}	=	Mass of Cement Produced
Clinker	=	Mass of Clinker
Cement	=	Mass of Cement
RM	=	Mass of Raw Material
$CaCO_{3\ \text{equivalent}}$	=	Mass of $CocO_3$ equivalent
$CO_{2\ (m.w.)}$	=	Molecular weight of CO_2
$CaCO_{3\ (m.w.)}$	=	Molecular Weight of $CaCO_3$

clinker, and be sure to include any exported clinker in the calculated clinker content of the produced cement.

Step 3: Determine the amount of raw material used. To determine the amount of raw material required to produce the quantity of clinker identified in Step 2, multiply the quantity of clinker by the raw material ratio. The raw material ratio includes the amount of material needed to produce the quantity of clinker as well as accounts for losses in CKD.

Step 4: Determine the amount of $CaCO_3$ equivalent used to produce clinker. The $CaCO_3$ equivalent factor should be provided by type of clinker, if available. Otherwise, default coefficients could be used, see Section 4.2. This factor should account for any $MgCO_3$ used but can be reported as $CaCO_3$ equivalent.

Step 5: Calculate the CO_2 emitted. To obtain the total metric tons of CO_2 emitted, multiply the limestone quantity by the $CO_2/CaCO_3$ stoichiometric ratio: atomic weight of CO_2 (44g)/atomic weight of $CaCO_3$ (100g) = 0.44.

Choice of Method for Estimating CO_2 Emissions

As mentioned, the clinker-based and cement-based approaches both theoretically yield the same amount of CO_2 emissions, assuming that accurate and precise data is available. Therefore, the choice of method to be used for estimating greenhouse gas emissions within the cement production industry is dependent on data availability. If data is collected on clinker production and the CaO/MgO content of the clinker is known then the clinker-based approach is the recommended approach to use. However, if data is collected on amount of cement produced, the raw material ratio, and $CaCO_3$ equivalent content of the raw material, then the cement-based approach is the preferred method.

Choice of Activity Data and Emission Factors

This section identifies specific issues related to the choice of activity data and emission factors used in the preceding emissions calculations.

4.1. Activity Data

Required data for cement production or clinker production needs to be reported in mass units. If the clinker-based method is used, clinker production data by type is preferable to account for the possible variations in CaO/MgO content of the different clinkers. Plant data should ideally include possible non-carbonate sources of CaO and MgO used in clinker production.

The clinker-based approach also requires data on the quantity of disposed CKD. This can be broken into categories of bypass dust and CKD as each can have a different level of raw material calcination. If specific values are not known, the default is to assume that the amount of CKD disposed of is equal to 2% of total clinker production.

The cement-based approach requires data on the amount of cement produced. This should be reported by cement type to account for the possible variations in clinker content of the different cement types. Plant data should ideally include imports and exports of clinker to account for the total amount of clinker produced by the facility.

4.2. Emission Factors

The clinker-based approach requires an emission factor in terms of mass CO_2/mass clinker. This factor is calculated based on the percent of CaO and MgO in the clinker. The factor should be specific for each type of clinker produced and adjusted to account for any imported CaO or MgO. The factor should only include CaO or MgO content that comes from calcined $CaCO_3$ or $MgCO_3$. Any CaO or MgO added directly to the kiln (e.g., from alternate fuels or raw materi-

Example Calculation of CO_2/Clinker Emission Factor

An example calculation assumes 1 metric ton clinker produced at 65% CaO and 2% MgO by mass. It also assumes that there were imports of 30 kg CaO per metric ton of clinker through the use of alternate fuels and raw materials. The rest of the CaO and MgO in the clinker resulted from calcination of $CaCO_3$ and $MgCO_3$ at the facility.

To obtain the total metric tons of CO_2 emitted, subtract imported CaO and MgO from the total and multiply the remaining quantity of CaO and MgO by their corresponding stoichiometric ratios. The CO_2/CaO stoichiometric ratio: atomic weight of CO_2 (44g)/atomic weight of CaO (56g) = 0.785. The CO_2/MgO stoichiometric ratio: atomic weight of CO_2 (44g)/atomic weight of MgO (40g) = 1.09.

(0.65 metric tons CaO – 0.03 metric tons CaO) × 0.785 = 0.487 metric tons CO2

0.02 metric tons MgO 1.09 = 0.022 metric tons CO_2

Total = 0.487 + 0.022 = 0.509 metric tons or 509 kg CO_2/metric ton clinker als) should not be included in this factor. If no information is known on the CaO/MgO content of the clinker a default value of 525 kg CO_2/metric ton of clinker can be used[6].

The clinker-based approach also requires a factor for CO_2 emissions per mass of CKD. It is possible that the CKD will contain $CaCO_3$ and $MgCO_3$ that has not been calcined. Therefore, use of the same emission factor used to estimate clinker emissions could overestimate emissions from CKD. The CKD emission factor can be determined based on the clinker emission factor and a degree of CKD calcination. The relationship between the degree of CKD calcination and the CO_2 emissions factor is non-linear. It can be approximated with Equation 3[7]:

For the cement-based approach there are three factors that have to be considered; the clinker to cement ratio, the raw material ratio, and the raw material $CaCO_3$ percent. Each one should be determined for each different type of cement produced. The clinker to cement ratio should account for any addition of pozzolans and other admixtures. If data is not known, default factors of 0.95 metric tons clinker per metric tons cement can be used for portland cement and 0.75 metric tons clinker per metric ton of cement can be used for blended cements.

The raw material ratio accounts for the amount of raw material needed to produce an amount of clinker. It also accounts for any losses in the form of CKD. If site specific data is not known, a default factor of 1.54 can be applied. This default ratio indicates that 1.54 metric tons of raw mix will produce 1 metric ton of clinker and an unspecified amount of CKD.

The raw material $CaCO_3$ equivalent percent should account for any $MgCO_3$ used in the raw mix. This factor should be calculated on a site and type of clinker specific basis. To convert $MgCO_3$ into a $CaCO_3$ equivalent amount, multiply the amount of $MgCO_3$ by 1.19. For example, 1 kg of $MgCO_3$ results in the same amount of CO_2 emissions as 1.19 kg of $CaCO_3$. The percent

Equation 3: Estimation of CKD CO_2 Emission Factor

$$EF_{CKD} = \frac{\dfrac{EF_{Cli}}{1 + EF_{Cli}} \times d}{1 - \dfrac{EF_{Cli}}{1 + EF_{Cli}} \times d}$$

where:

EF_{CKD} = Emission Factor of partially calcined Cement Kiln Dust $\left(\frac{massCO_2}{mass\ CKD}\right)$

EF_{Cli} = Plant specific Emission Factor of clinker $\left(\frac{massCO_2}{mass\ clinker}\right)$

d = Degree of CKD calcination (released CO_2 as % of total carbonate CO_2 in the raw mix)

6 The Cement CO_2 Protocol: CO_2 Emissions Monitoring and Reporting Protocol for the Cement Industry, *Guide to the Protocol, Version 1.6,* October 19, 2001, World Business Council for Sustainable Development Working Group Cement.

7 Ibid.

factor should not include any non-carbonate sources of CaO or MgO. If specific data is not known, a default factor of 78% can be used indicating that the raw mix is 78% $CaCO_3$ equivalent by mass.

The cement-based methodology assumes total calcination of all limestone feed through the tons raw meal ratio. Therefore, it is assumed that all raw mix that goes to clinker as well as CKD is completely calcined. This could lead to an overestimation of emissions if not all of the $CaCO_3$ and $MgCO_3$ in the CKD is calcined. In order to account for uncalcined raw mix, the raw material ratio or the raw material to $CaCO_3$ percent should be adjusted.

For both the clinker-based and the cement-based methods a Loss On Ignition (LOI) test can be used to calculate emission factors as opposed to based on percent concentrations of calcined materials. LOI data represents CO_2 release from the $CaCO_3$ and $MgCO_3$ in the raw mix under high temperature. This LOI data can be converted to equivalent $CaCO_3$ using molecular weight ratio of CO_2 and $CaCO_3$.

Completeness

An assessment of CO_2 emissions from cement production must be complete from a corporate as well as a facility level basis. From a corporate perspective, the inventory should include emissions from all types of cement produced in all facilities included in the corporate inventory as determined by their organizational boundaries. This is addressed in Chapters 2 and 3 of the *Climate Leaders Design Principles* that discusses setting the boundaries of the corporate inventory.

Completeness of corporate wide emissions can be checked by comparing the list of facilities included in the GHG emissions inventory with those included in other emission's inventories/environmental reporting, financial reporting, etc. The GHG inventory should also be complete at the facility level and include all types of cement or clinker produced by that facility.

The inventory should also accurately reflect the timeframe of the report. In the case of Climate Leaders, the emissions inventory is reported annually and represents a year of emissions data. Therefore, the inventory should include all the cement or clinker produced during the reporting year in order to be complete.

Uncertainty Assessment

There is uncertainty associated with calculating CO_2 emissions from all sources. As outlined in Chapter 9 of the *Climate Leaders Design Principles,* Climate Leaders does not require Partners to quantify uncertainty as +/- % of emissions estimates or in terms of data quality indicators. It is recommended that Partners attempt to identify the areas of uncertainty in their emissions estimates and make an effort to use the most accurate data possible.

Uncertainties in estimating CO_2 emissions from cement production may be the result of several factors. Both the clinker-based and cement-based methods are subject to uncertainty in the accuracy of the reported weight measurements, i.e., cement and clinker production tonnage, or raw material consumption tonnage. The largest source of uncertainty associated with the cement-based method is the clinker to cement ratio. The ratio is dependent on the type of cement blend produced.

The clinker-based method uses CaO and MgO contents of clinker to estimate emissions. There may be non-carbonate sources of CaO and MgO used in the raw mix. If these sources are minimal then the estimated error will be within 1–2%. However, these other sources may be much larger. The quantity of CaO and MgO associated with these other non-carbonate sources would need to be subtracted from the total estimated CaO and MgO quantities to prevent over-estimation of greenhouse gases.

If the CO_2 emissions associated with the decomposition of $MgCO_3$ are neglected, this will lead to an underestimation of CO_2 emissions. The typical MgO content of clinker is usually about 2%.

Reporting and Documentation

Partners are required to complete the Climate Leaders *Reporting Requirements* for cement production along with their other sources of emissions and report them annually. Partners should report the data listed in Table 2 below. In order to ensure that estimates are transparent and verifiable, the documentation sources listed should be maintained. These documentation sources should be collected by the company to ensure the accuracy and transparency of the data.

Table 2: Documentation for Cement Production Emission Sources

Data	Documentation Source
Cement Production/Clinker Production/Raw Material Consumption—Quantity and Type	Delivery receipts; contract purchase or firm purchase records; stock inventory documentation; and operator daily/weekly/monthly production reports
Clinker Content Ratios	Operator daily/weekly/monthly production reports

Inventory Quality Assurance/Quality Control

Chapter 9 of the *Climate Leaders Design Principles* provides general guidelines for implementing a QA/QC process for all emission estimates. For cement production sources, activity data and emission factors can be verified using a variety of approaches:

- Checks should ensure that the best and most accurate emission factors are being used. If custom emission factors are available, are there any significant differences with the default numbers?
- Loss on Ignition (LOI) tests can be performed to determine emission factors or to compare against estimated factors.
- The amount of CKD discarded should be tracked and the degree of CKD calcination should be monitored.

CLIMATE LEADERS
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